Precipitation in Cyclones

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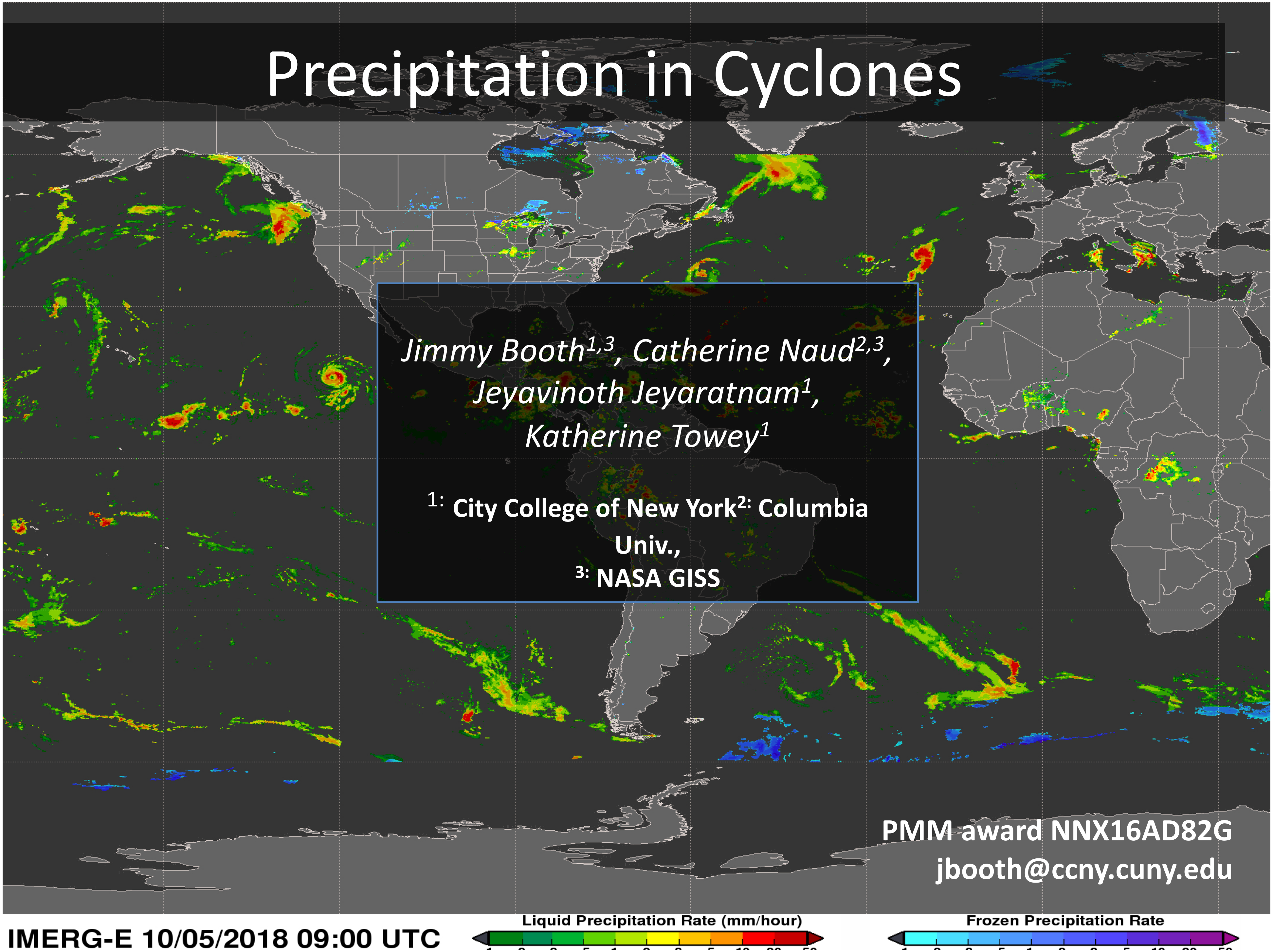


INTRODUCTION

- Extratropical cyclones generate the majority of total and extreme precipitation in the midlatitudes

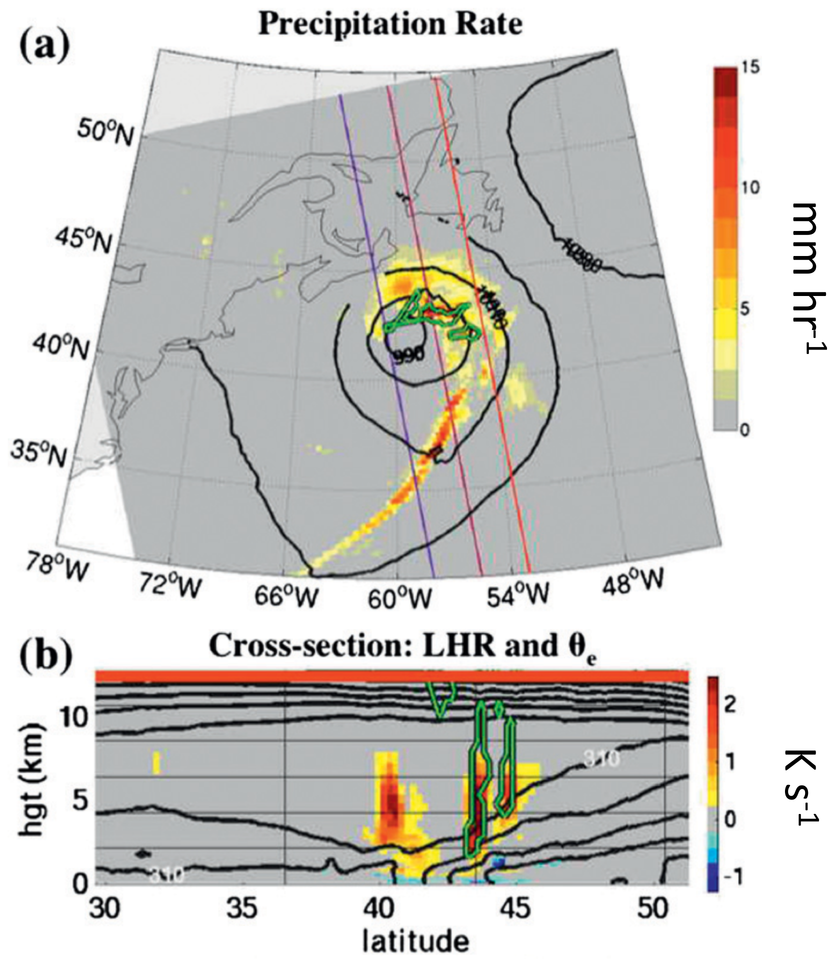
- The <u>latent heating associated with the generation of precipitation</u> strengthens the wind circulation in the cyclones

$$\frac{d(PV)}{dt} = -g(\zeta + f)\frac{\partial \dot{\theta}}{\partial p}$$

PV: potential vorticity

$\dot{\theta} =$ diabatic heating rate

Numerical Modeling Example

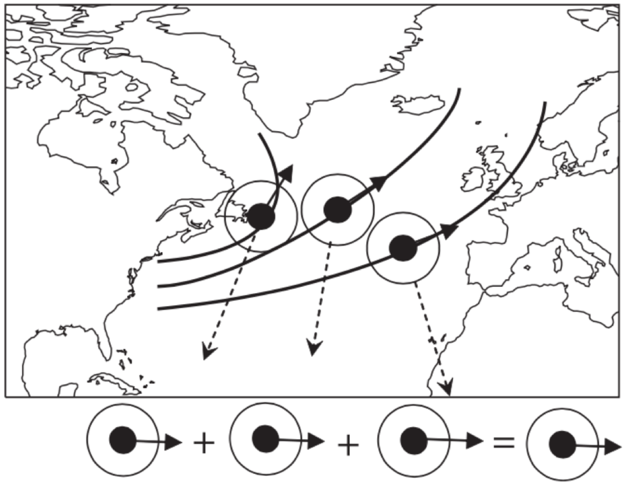


Booth et al. 2012

METHODS: Cyclone-centered compositing

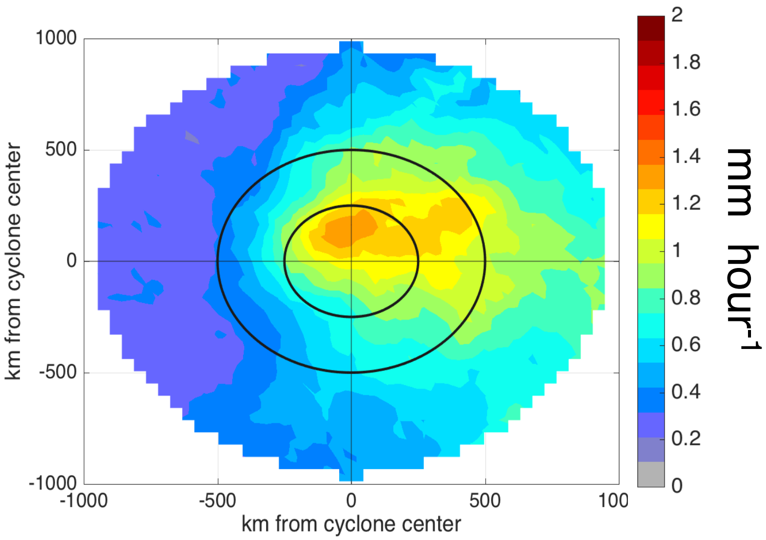
1. Find cyclones based on central pressure
2. Link cyclones in time to create tracks
3. Extract data around center of each storm
4. Average multiple cyclone-centered data
5. For SH: flip N/S orientation of the cyclone
6. Examine the precipitation for a specific point in the storm life cycle.

The resulting composite does not look like an individual cyclone, and instead should be thought of as a cyclone-relative 2-D histogram of precipitation frequency, weighted by precipitation strength.



from Catto et al. 2010

Cyclone-centered
IMERG precipitation



Outline for Results

- Analysis 1:

Does reanalysis properly capture precipitation rates and frequency in extratropical cyclones?

- Analysis 2:

How much precipitation is generated by upright convection in extratropical cyclones?

- Analysis 3:

What is the temporal relationship between the life cycle of precipitation and circulation within extratropical cyclones?

- Analysis 4:

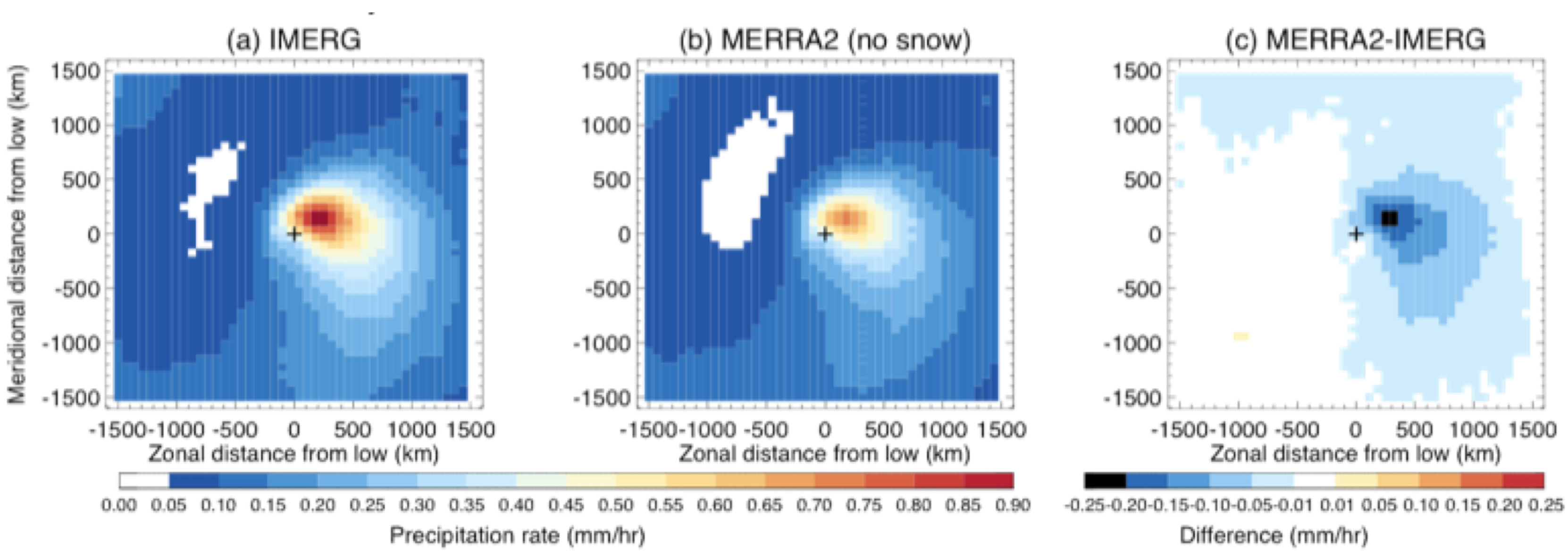
How much precipitation is generated by hurricanes that do and do not undergo extratropical transition as compared to extratropical cyclones?

Analysis 1: (<u>*metrics*</u>) Extratropical Cyclone Precipitation in MERRA2

METHODS

- IMERG is averaged is an identical longitude-latitude grid as MERRA-2 (i.e. 0.625°x0.5°) and over an hour
- All precipitation rates less than 0.025 mm/hr are set to 0 (see Tan et al. 2017)
- The composites are purely over open-ocean; snowfall is not included.

Total Precipitation in NH+SH all seasons ETC in 30 – 60 N/S

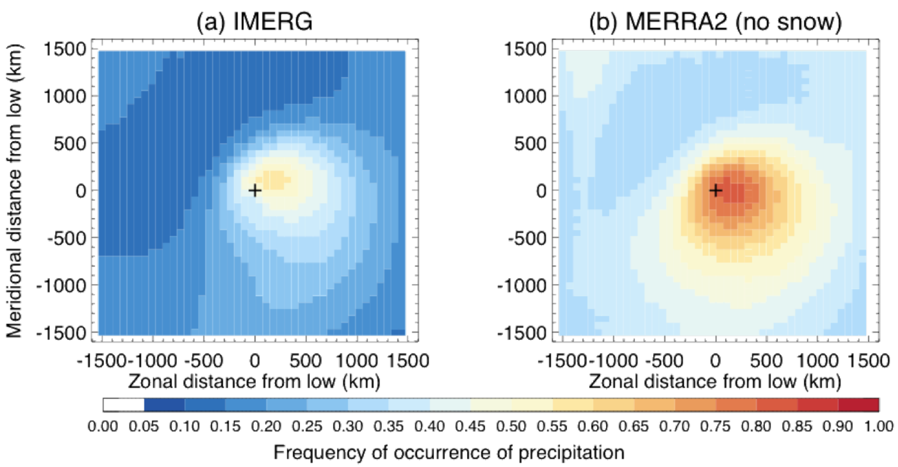


Same spatial distribution, but MERRA-2 < IMERG in comma

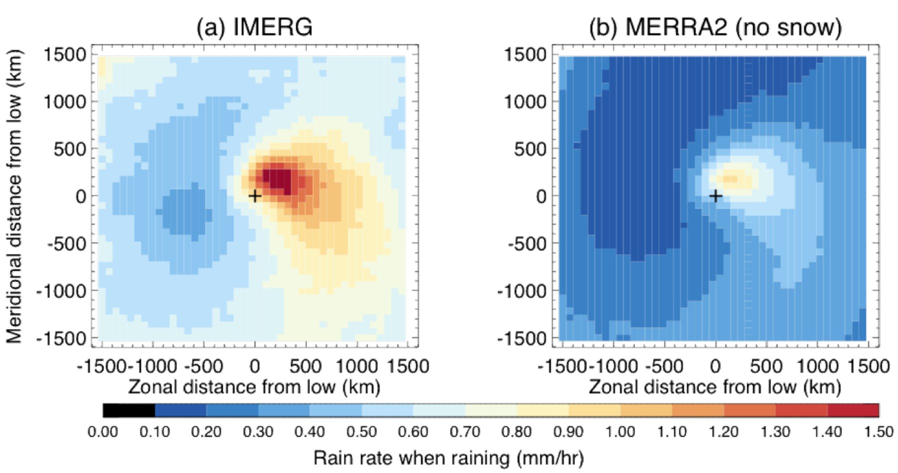
Where precipitation is largest => bias largest, i.e. MERRA-2 predicts up to 0.25 mm/hr less precipitation than IMERG

Analysis 1: Extratropical Cyclone Precipitation in MERRA2

Decompose into frequency of occurrence and rain rate when raining



Take away: MERRA-2 generates rain more frequently than IMERG

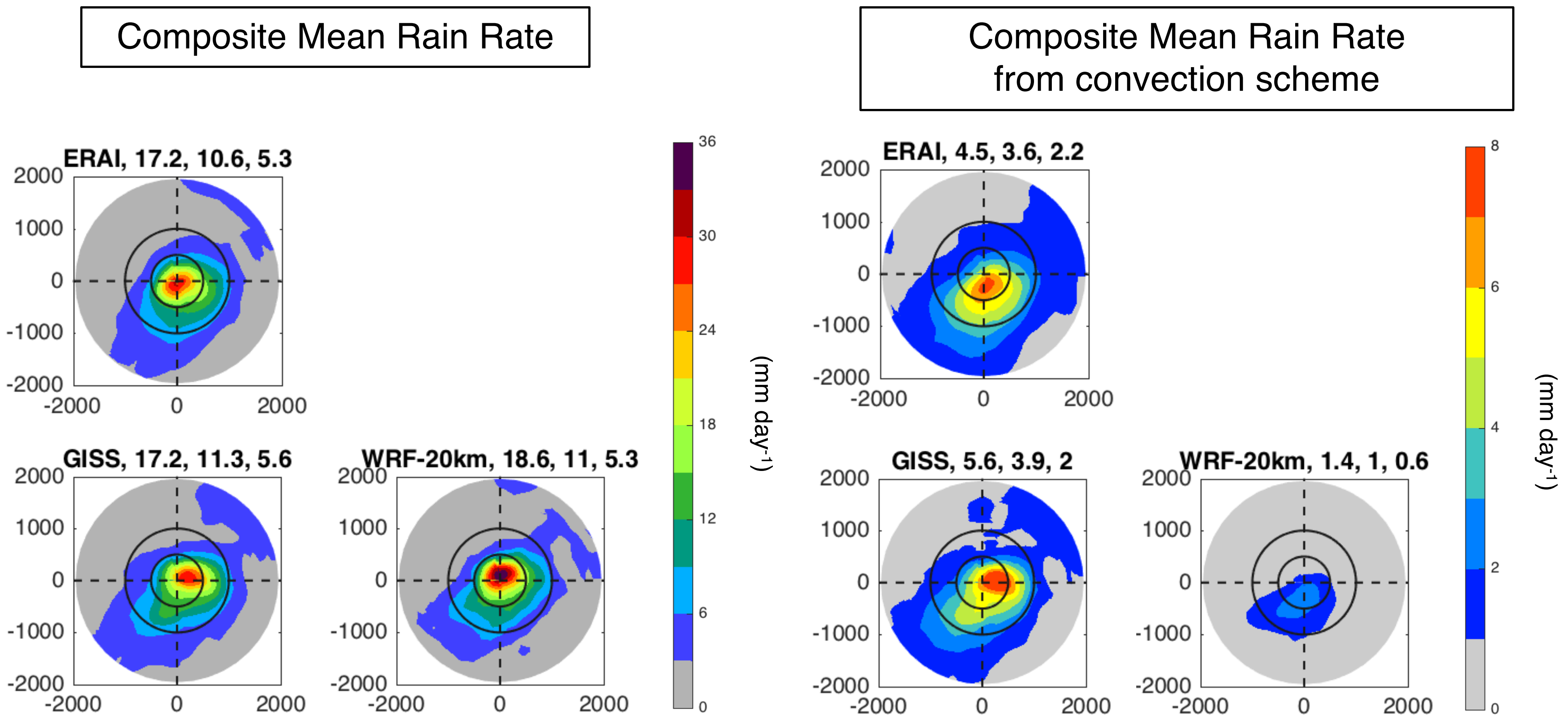


Take away: When it does rain, MERRA-2 generates weaker rain rates than IMERG.

=> Largest relative differences are in area of relatively low precip might be related to parameterization of convection.

This issue is not unique to MERRA2. There is a similar issue in ERA-Interim.
For full details: talk with Catherine Naud (or see her poster via a DeLorean)

Analysis 2 Motivation:
Prior work on Reanalysis vs Model Precipitation



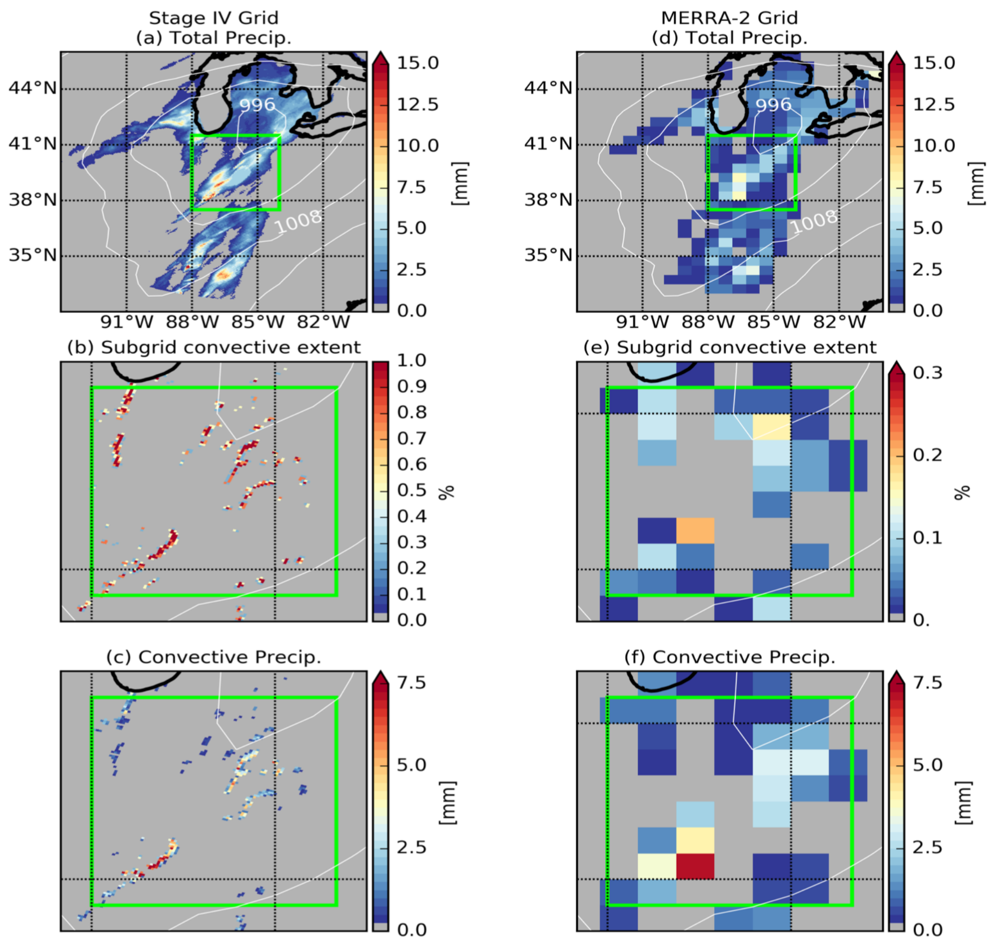
Note the different color scales.

Take away: variability in convective precipitation as large as total.

Booth et al., JCLI, 2018

Analysis 2: (*processes/metrics*) Convection in Extratropical Cyclones using ground-based radar

Example ETC: March 24th, 2016



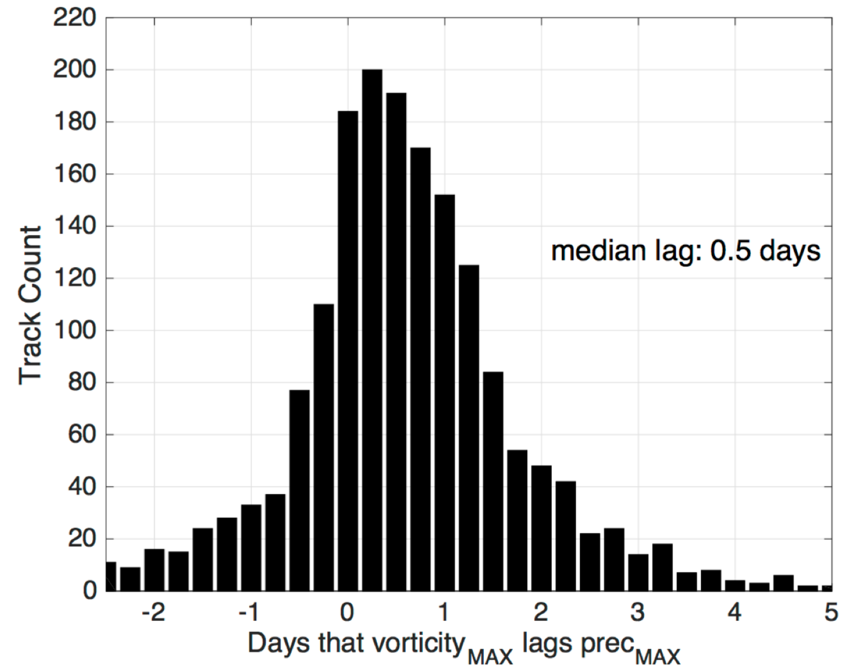
- At 4km resolution, upright convection occurs in 1-5% of the precipitation footprint of the extratropical cyclone.
- If the data is re-gridded to a GCM resolution, upright convection occupies 30-40% of the precipitation footprint.
- The majority of upright convection occurs ahead of the cold front in the warm sector. The convection disperses into other regions as the cyclone ages.

This is preliminary work for planned analysis of GPM-CMB data

For full details: see my poster today.

Analysis 3: (*processes*) Cyclone-centered precipitation using IMERG and precipitable water vapor (PWV) using reanalysis

Top panel: For each cyclone track find the difference in timing of precip max and vorticity max.



- Not a new result (Bengtsson et al. 2009; Catto et al. 2010; Rudeva and Gulev, 2010; also many case studies)

- Mystery is: what explains the lag in timing?

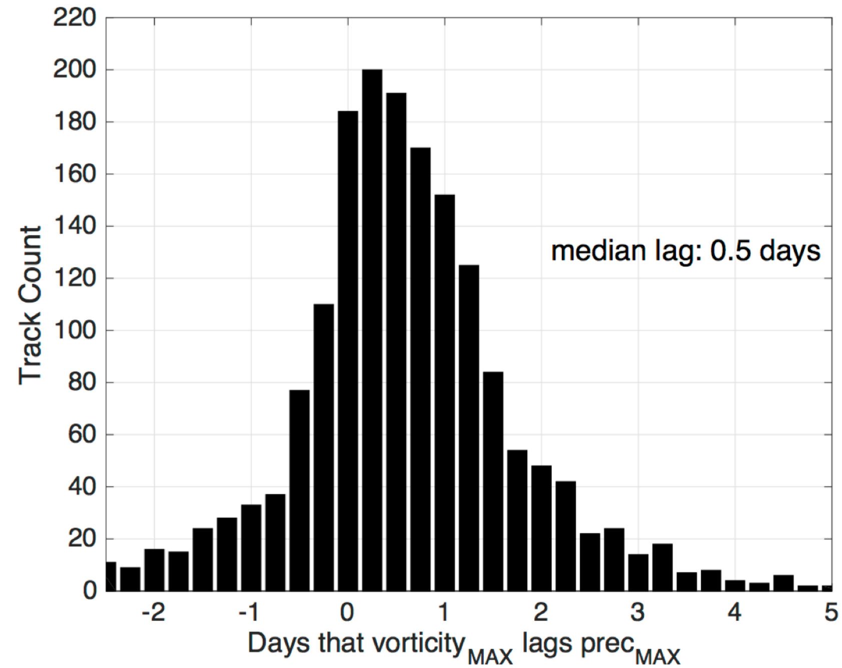
Dynamical adjustment to thermodynamic forcing?
The cyclones move north, cutting off PWV?

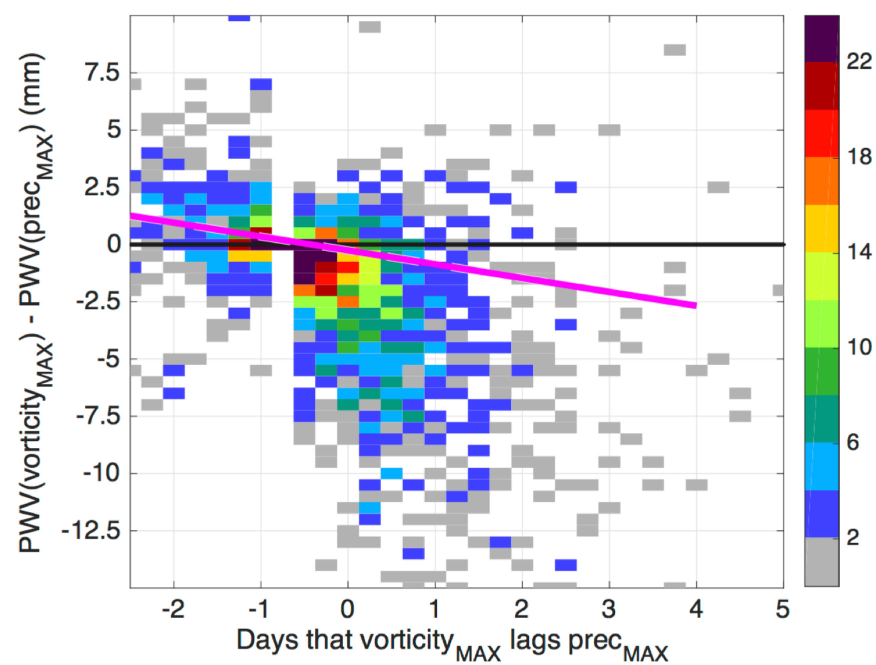
Analysis 3: (*processes*) Cyclone-centered precipitation using IMERG and precipitable water vapor (PWV) using reanalysis

Top panel: For each cyclone track find the difference in timing of precip max and vorticity max.

Bottom panel: For each cyclone track compare the difference in the timing of precip and 850-hPa relative vorticity and the difference in PWV at the time of precip max and vorticity max.

Take away: the vorticity max lags the precipitation max, but there is less PWV in the cyclone at the time of vorticity max.

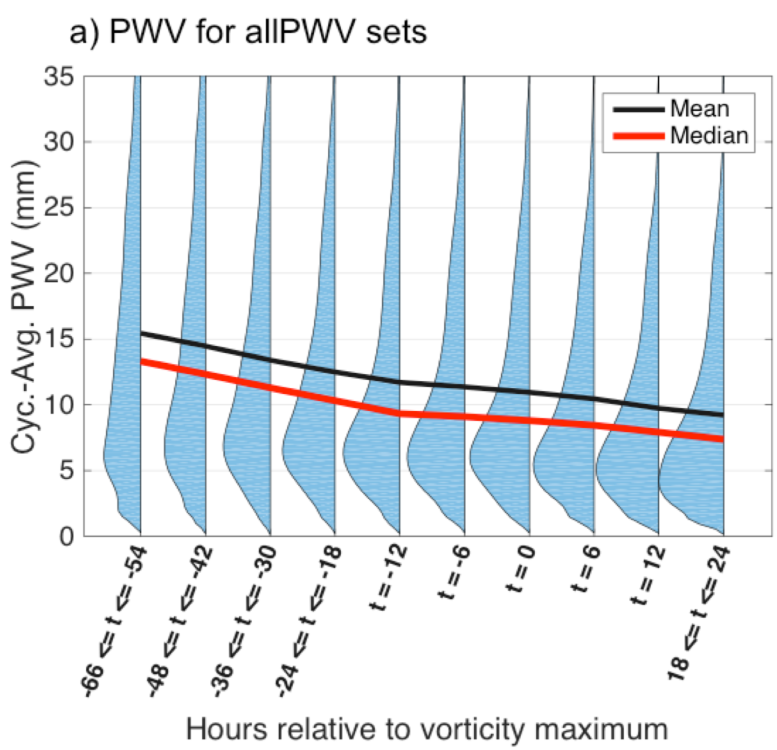


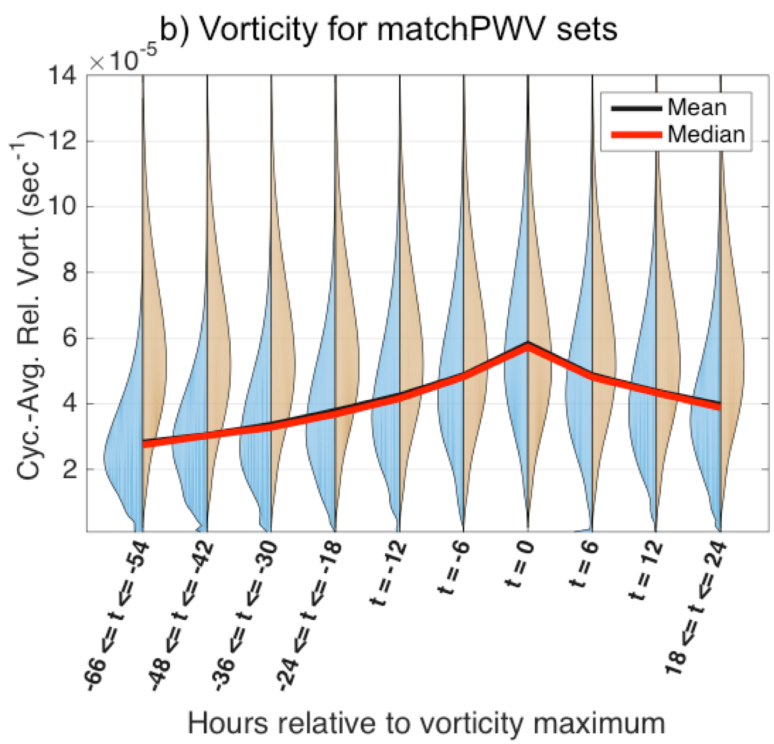


Analysis 3: Cyclone-centered precipitation using IMERG and precipitable water vapor (PWV) using reanalysis

Next we consider the average behavior using large sets of cyclones ~ 1000

Set #1: allPWV: Cyclones sorted based on their vorticity.
Set #2: matchPWV: sub-sample the age subsets so that they all have the same distribution of PWV.

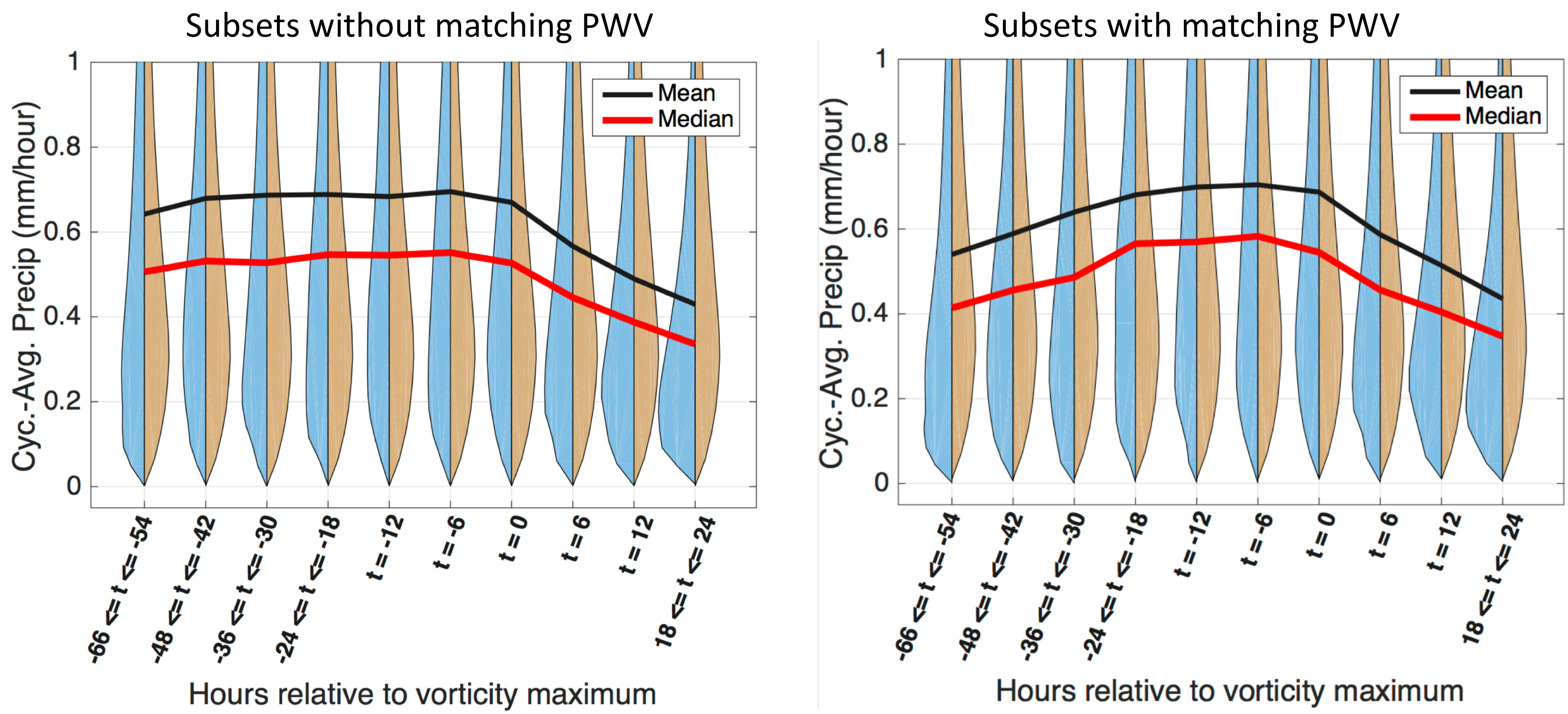




Blue: distribution at time shown on x-axis
Orange: distribution at t = 0.

Analysis 3: Precipitation Life Cycles using IMERG

Cyclone-total Precipitation Distributions for 0 – 1 mm/hr



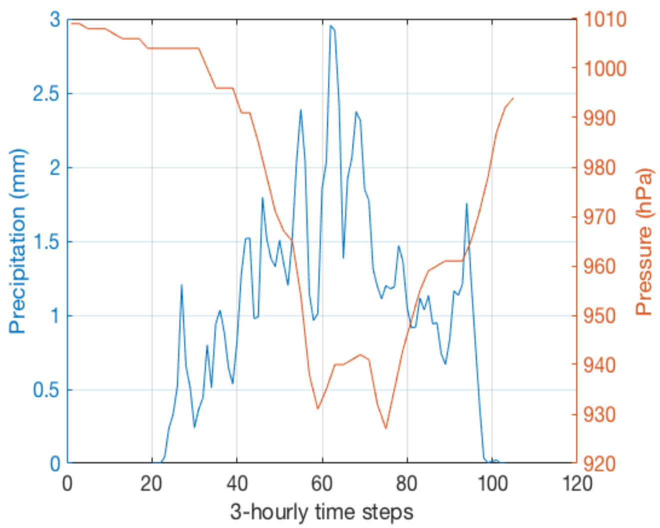
Blue: distribution of at time shown on x-axis, Orange: distribution at t = 0.
Black/Red line: mean/median for all cyclones per life cycle.

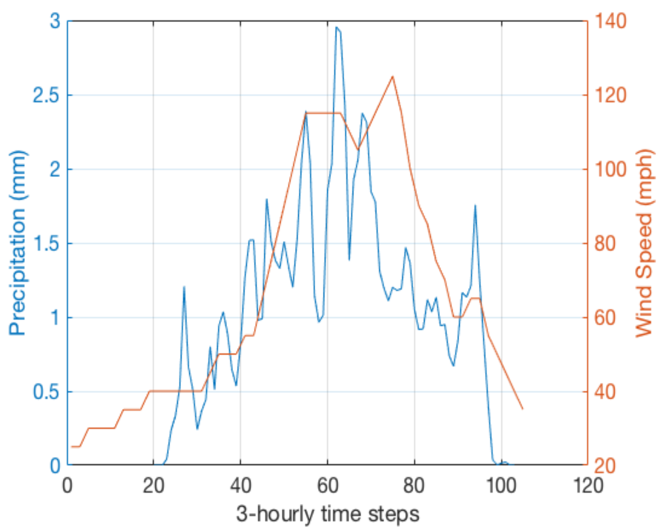
***Take away**: If we force PWV distributions to match, timing of peak in precipitation and vorticity converge, i.e., lag in timing is mainly related to PWV availability, not thermodynamic/dynamic coupling.*

Booth et al., GRL, 2018

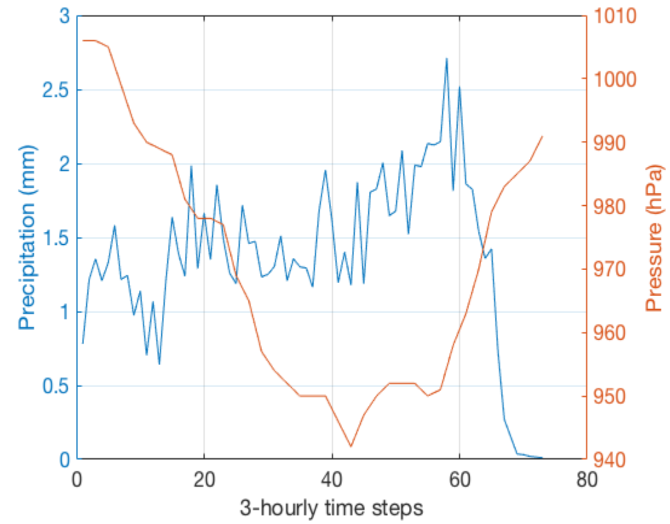
Precipitation Life Cycles in hurricanes using using TMPA

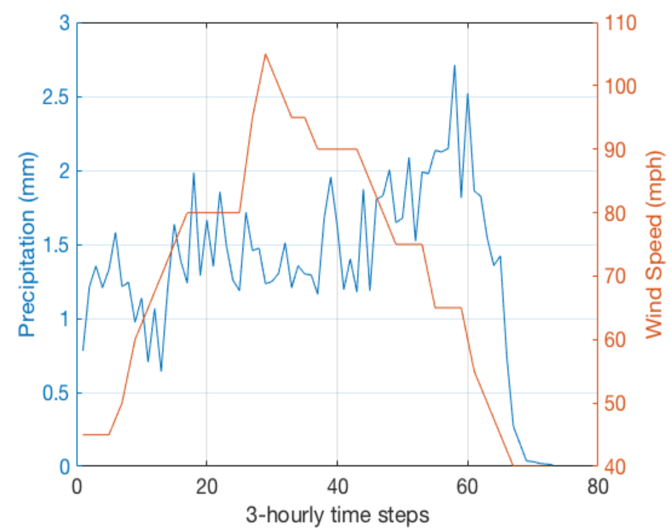
Earl, 2010 (nonET)





Irene, 2011 (ET)



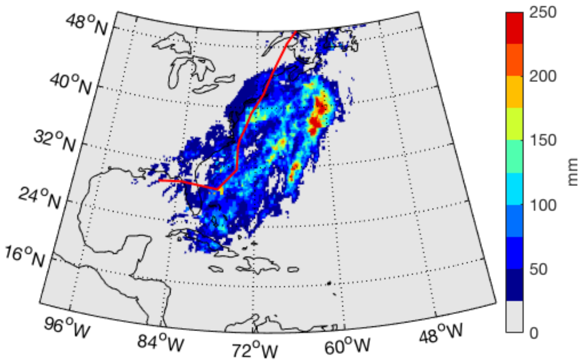


Analysis 4: (*hazards*) Comparing ETCs, TCs, and ET-transitions

Methods: Use the TMPA (i.e., TRMM-3B42) dataset to calculate cyclone-accumulated precipitation

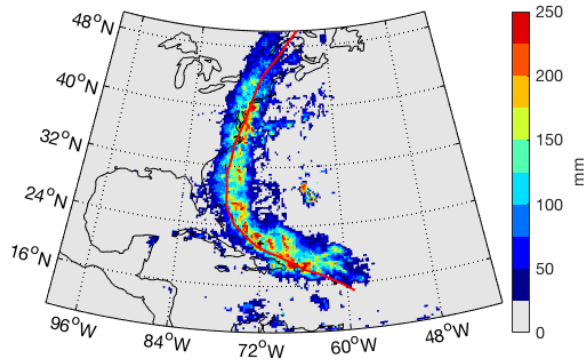
ETC Example:

24 – 27 Jan 2000



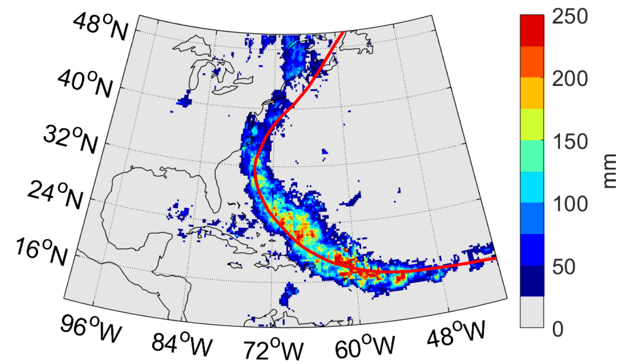
Total rainfall:
168,111 mm

ET Example:
Hurricane Irene
21 – 30 Aug 2011



Total rainfall:
191,115 mm

nonET Example:
Hurricane Earl
24 Aug – 6 Sept 2011



Total rainfall:
169,030 mm

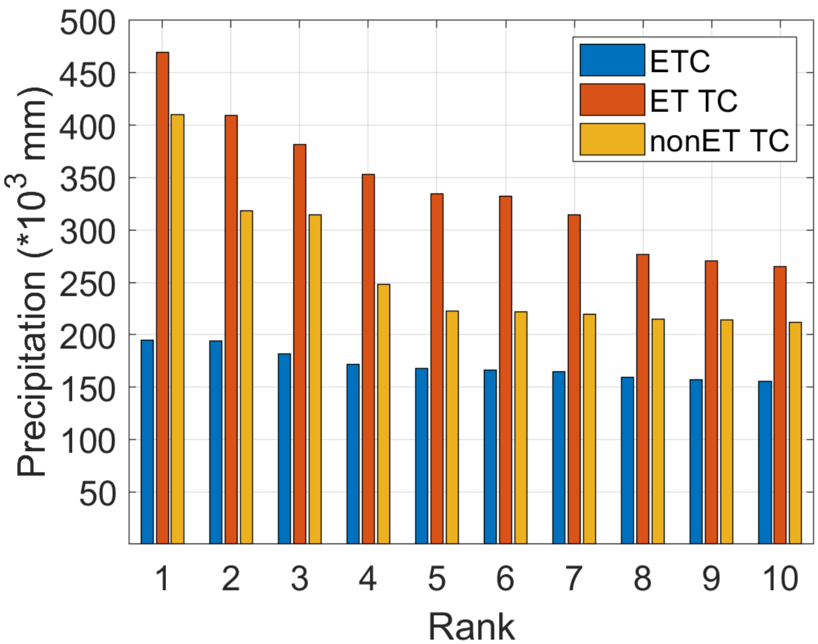
Cyclone-relative Search radius 1500 km

We repeated this analysis for all ETCs and TCs in the TMPA record, and then carried out a set of statistical analyses.

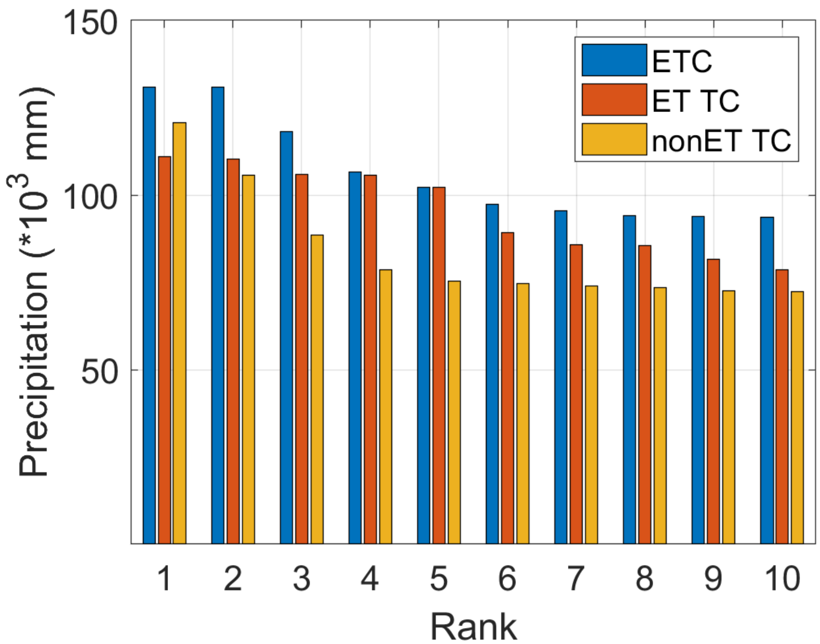
Analysis 4: (hazards) Comparing ETCs, TCs, and ET-transitions

Example result: comparing the top 10 events in the TMPA record

Accumulated Lifecycle Precipitation



Maximum 2-day Precipitation



Take Away: (1) total life cycle: Hurricanes that undergo ET generate the most precip. (2) for 48-hour totals: ETCs are comparable to ET events.

- See my poster today for more details
- Future plans: apply the analysis to IMERG.

SUMMARY AND CONCLUSIONS

1. Reanalyses have the following biases: generate too much light rain and not enough heavy rain in extratropical cyclones (ETCs).

2. Upright convection does occur in ETCs over land, but it is disperse in location and not necessarily co-located with the strongest precipitation rates.

3. The fact that precipitation peaks in ETCs prior to the peak in cyclone vorticity is more likely related to PWV availability than a delay in the dynamical response to the latent heating.

4. Over the total life cycle of a cyclones: Hurricanes that undergo extratropical transition (ET) generate the most precipitation, however for 48-hour totals: ETCs are comparable to ET events.

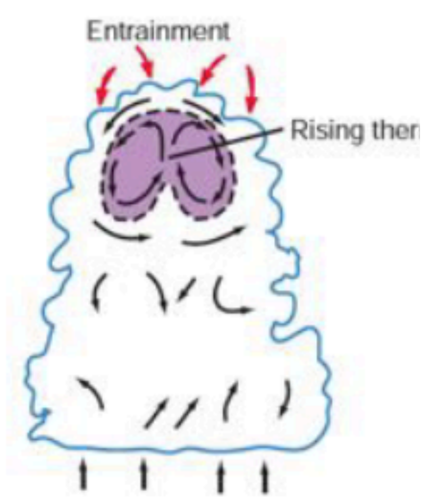
Thank you for you attention. Jimmy Booth jbooth@ccny.cuny.edu

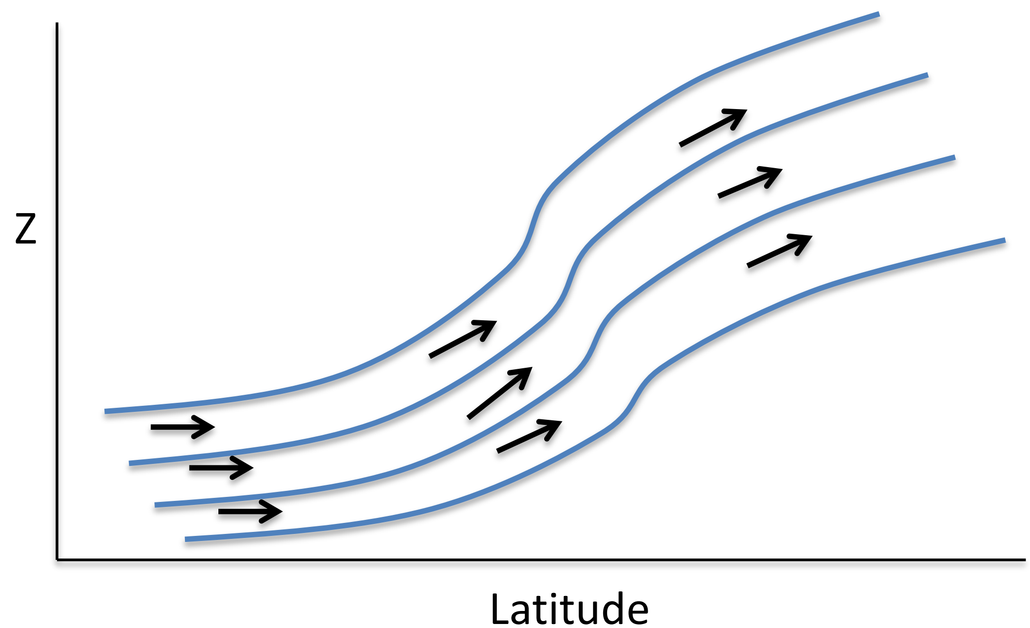
EXTRA SLIDES

INTRODUCTION

What are the ingredients for precipitation ?

1. Moisture flux convergence
2. Lifting, which, can occur through three possible mechanisms
   - Convective ascent related to buoyant instability
   - Forced adiabatic ascent related to convergence and divergence in response to baroclinic instability.
   - Slantwise convective ascent





INTRODUCTION

In extratropical cyclones, is there a competition for moisture between convective and isentropic ascent?

Boutle et al., QJRMS 2011
Numerical modeling study of idealized baroclinic wave ----------->

moisture within warm conveyor belt: dynamically important to storm

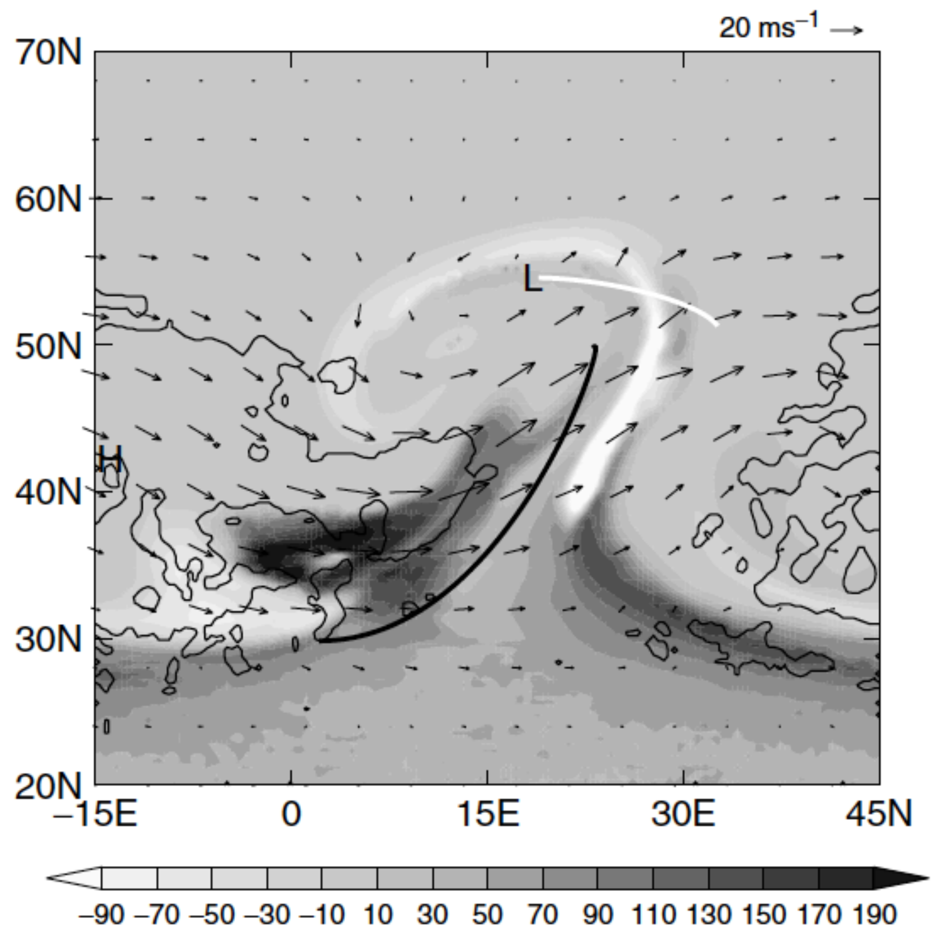
moisture south of storm: less influence on dynamics

$$\frac{d\left(PV\right)}{dt}=-g\left(\zeta+f\right)\frac{\partial\dot{\theta}}{\partial p}$$

PV: potential vorticity

$\dot{\theta} =$ diabatic heating rate

Tracer concentration
Model with convection parameterized minus model without convection
arbitrary units; white: less, black: more



Analysis 1: Cyclone-centered precipitation using IMERG and precipitable water vapor (PWV) using reanalysis

Cyclone Precipitation Rates

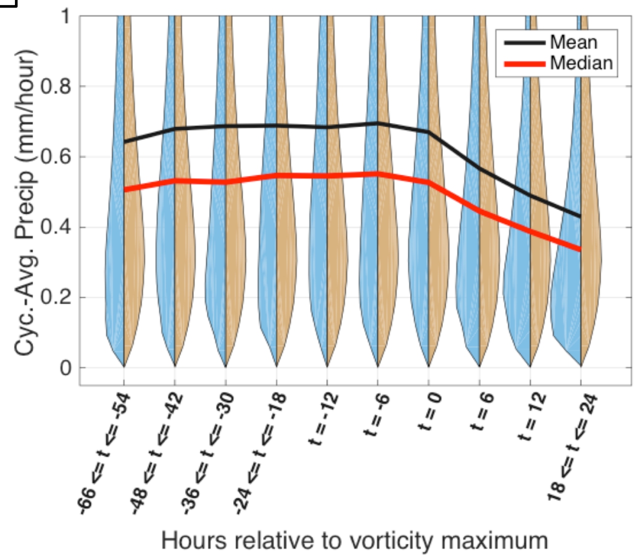
Blue: distribution of at time shown on x-axis
Orange: distribution at t = 0.

Black line: mean for all cyclones per life cycle.

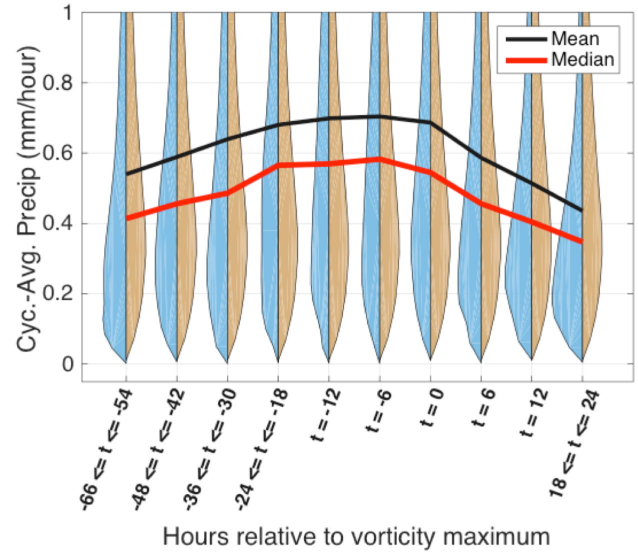
Red line: median for all cyclones per life cycle.

Take away: If we force the PWV distributions to match, the timing of peak in precipitation and vorticity converge for both the overall mean and the extremes.

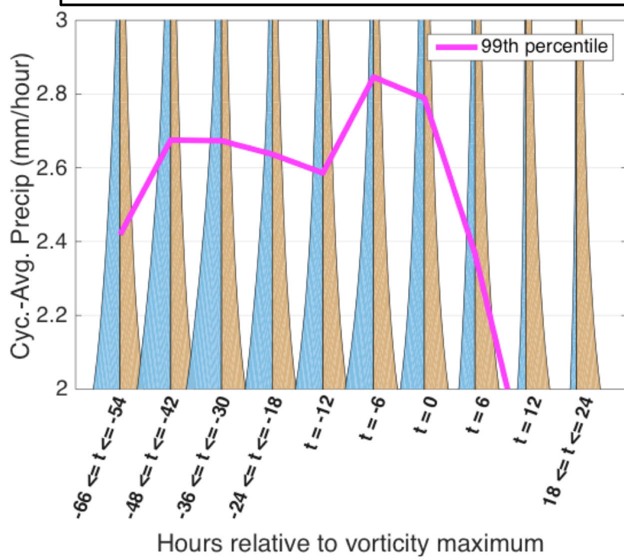
Sets without matching PWV

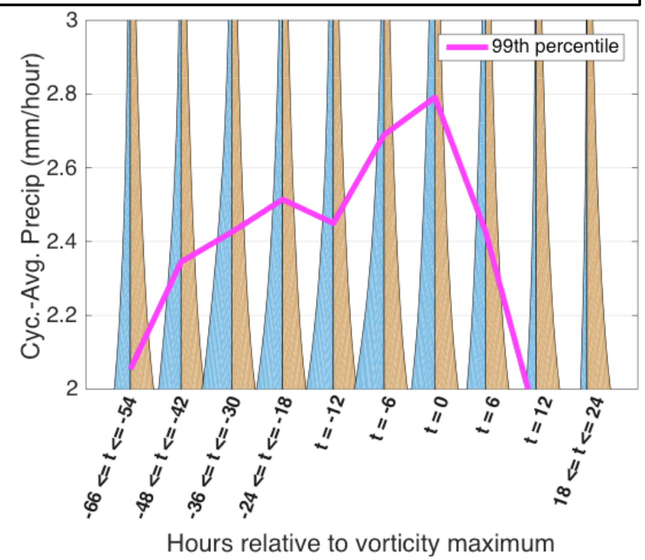


Sets with matching PWV



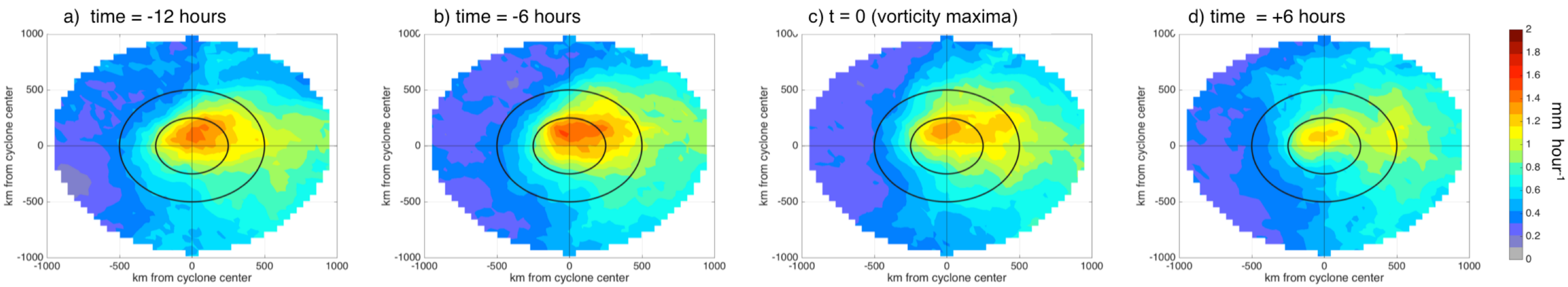
Top panels: distributions for 0 – 1 mm/hr; Bottom: 2 – 3 mm/hr





Analysis 1: Cyclone-centered precipitation using IMERG and precipitable water vapor (PWV) using reanalysis

Cyclone Precipitation Composites
Time evolving relative to vorticity maxima



Take away: prior to peak in vorticity, precipitation falls more often close to the ETC center.

What is the cause of the lag in timing of peak vorticity intensity?

- The ETCs move poleward as they strengthen, decreasing PWV available.

- The size of the warm sector decreases as cold front catches up to warm front.

Booth et al., GRL, 2018

Analysis 2: Extratropical Cyclone Precipitation in MERRA2

Comparison with ERA-interim: PW > 19 mm

1. We apply the same technique, the cutoff at ERA-interim 1° x1° 6-hourly is 0.006 mm/hr.
2. We cannot remove land/sea ice => should be of no consequence
3. But more importantly: snowfall cannot be removed from ERA-i => impose cyclone-wide mean PW > 19 mm
4. For PW > 19 mm: MERRA-IMERG (top) and ERAI-IMERG (bottom) for: total precip, rain rate and frequency

- MERRA-2 comparison similar for the PW > 19 mm cyclone vs all cyclones (NH vs SH also similar)
- For ERA-interim: similar sign distribution of differences except in lower left quadrant: rain rates ERAI > IMERG

=> differences presumably real as differ between 2 reanalysis. Both predict light rain more frequently than IMERG in cold sector but ERA-interim also predicts higher rain rates than both IMERG and MERRA-2